Cost Analysis of Experimental Treatments on Ponderosa Pine Watersheds

by James M. Turner and Frederic R. Larson

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Abstract

A regression model predicts thinning and piling costs as a function of the degree of timber basal area removed. Thinning costs are related to basal area removed noncommercially, while piling costs are related to total basal area removals including commercial logging. Sensitivity analyses indicate that the piling predictive models are representative for all but the most extreme conditions of slope steepness likely to be encountered in the Southwest. If thinning involved removal of trees larger than 8 inches in diameter, cost variability may be greater than that accounted for by the thinning model.

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The purpose of the Beaver Creek Pilot Watershed project is to evaluate the effects of vegetative changes on water, sediment, soil, forage, recreation, and wildlife yields, and to determine the subsequent risks from fire, insects, and disease. Located just south of Flagstaff, Arizona, this project is currently developing multiple use production data for alternative land management practices. A wide range of vegetation treatments have been experimentally tested on watersheds in both the juniper and ponderosa pine zones.

This report contains an analysis of treatment costs in the ponderosa pine zone to provide relationships for economic evaluations and estimation of project planning costs. The estimates include costs of precommercial thinning and slash disposal, by Forest Service crews (force account work), but not costs of commercial product removals. If thinning and piling activities are to be accomplished as sale purchaser work, or by contract, these estimates will also be useful for determining contract costs.

The activities and costs may be much the same as those required for present operational management, but the experimental treatments are more extensive. For example, where budget limitations restrict present management practices to slash piling in fuelbreaks only, the experimental treatments to date involved slash removal wherever timber was cut. A cost model which distinguishes between per-acre thinning and per-acre piling costs is thus suitable for both experimental and present management applications.

The system for collecting cost data was designed by Worley et al. (1965). Two papers have been published summarizing cost factors in the juniper vegetation type (Miller and Johnsen 1970, Miller 1971), and a third concerns the clearcutting of ponderosa pine (Miller and Larson 1973). This report combines data from the above pine clearcut treatment with that from four other treatments to form a basis for predicting costs for operations likely to be encountered in ponderosa pine watershed treatments. These five treatments encompass a wide range of configurations and degrees of vegetation removal, thereby providing a good cross section of activities and forest conditions which determine cost.

The study area contains cutover, uneven-aged stands comprised of 85 percent ponderosa pine and 15 percent woodland species, primarily Gambel oak and alligator juniper. Ponderosa pine averaged 2,000 cubic feet in volume and 110 square feet in basal area per acre.

The objectives of this report are to:

1. Present and compare costs for jobs encountered in experimental treatments of the southwestern ponderosa pine vegetation type.
2. Develop a cost prediction model for experimental and operational applications.
3. Use a sensitivity analysis to test the effects of labor, equipment, materials, slope steepness, and stand density on treatment cost.

Summary of Treatment Prescriptions

Regular 1/3 Stripcut, Watershed 9 (1,121 Acres, Treated in 1968)

Trees were cut in a pattern of alternating cut and leave strips oriented to the direction of landslope. The cut and leave strips, 60 and 120 feet wide, respectively, are regular in shape with few or no trees left in the cut strip. The leave strips were untreated, so only one-third of the watershed was harvested and treated. Saw logs

and poles were harvested; the slash was piled in windrows in the cut strips and burned (fig. 1).

Figure 1.—The regular pattern of cut strips on watershed 9.

Clearcut, Watershed 12
(455 Acres, Treated in 1967)

This treatment required complete removal of trees. The harvest included saw logs and poles. All slash and debris were windrowed in such a way as to trap and retain snow, and increase the watershed's drainage efficiency (fig. 2).

Irregular 1/3 Stripcut, Watershed 14
(1,350 Acres, Treated in 1970)

This pattern also consists of alternate cut and leave strips, which average 60 and 120 feet in width, respectively. Width of the clearcut strip varied as much as 50 percent (± 30 feet) in order to provide an esthetically pleasing, irregular pattern of elongated openings. The leave strips were thinned to 80 ft^2 basal area in a manner designed to improve timber production, while at the same time retaining sufficient density to encourage trapping and retention of snow in the adjacent cut strips. The harvest included saw logs, poles, pulpwood, and firewood. The slash was pushed into piles and burned. Spacers of uncut trees were left at intervals in the cut strips to break up visual continuity. Gambel oaks under 15 inches diameter at breast height were also left in the cut strips. The strips were generally oriented in the direction of landslope to facilitate water transport into stream channels (fig. 3).

Figure 3.—The cut strips of varying widths on watershed 14.

◄— Figure 2.—The clearcut area and slash windrowed to trap and retain snow on watershed 12.

Irregular 1/2 Stripcut, Watershed 16 (252 Acres, Treated in 1971)

This treatment is similar to the irregular 1/3 stripcut, except that both cut and leave strips were 60 ± 30 feet in width. Again, Gambel oak and spacers of ponderosa pine were left to break up the continuity of long cut strips. Leave strips were thinned to 80 ft^2 of basal area per acre to encourage timber growth. The harvest included saw logs, poles, and pulpwood.

Severe Thin, Watershed 17 (300 Acres, Treated in 1969)

After severe thinning, the remaining stand consisted of even-aged groups of ponderosa pine with crown density of 10 to 20 percent, and basal area of 25 ft^2 per acre. In addition to the pine, 5 to 10 ft^2 per acre of Gambel oak were left. The harvest included saw logs and poles; slash was piled in strategically arranged windrows for snow trapping and retention, and for water runoff (fig. 4).

Figure 4.—A severely thinned stand on watershed 17. Stands were thinned to a residual basal area of 25 square feet per acre.

Scope and Methodology

The data collection system developed by Worley et al. (1965) consisted of keeping daily time and material records for all jobs, such as thinning. The data are daily physical measures, such as hours of labor, hours of equipment rental, gallons of paint, rolls of flagging, etc., by job. Physical input-output data were collected rather than dollar costs and returns because it is easier to generalize from the former. The basic physical requirements for a given job are constant, and when multiplied by current wage rates and unit costs yield updated dollar cost estimates.

The approach used is quite similar to time-motion analysis aggregated to a daily basis. This strategy was chosen because the variability of conditions in the woods is far greater than under more closely controlled plant conditions. It is expected that widely varying factors such as soil, slope, and stand characteristics do affect treatment costs, and a later section explores these sources of variation.

Summary of Costs

Each watershed treatment is separated into operations, or jobs, to allow detailed examination of the component costs. Individual jobs encountered in the five treatments, in order of occurrence and by watershed, are listed in table 1. The component costs, consisting of supervision, labor, equipment, and materials, expressed on a per unit of material or per hour of labor and equipment, are given in table 2.

For practical purposes a distinction is made in this analysis between per-treatment-acre and per-watershed-acre costs. Because jobs such as thinning are not applied to the entire watershed, costs may be prorated over those acres actually treated (per-treatment-acre cost) or over the entire watershed (per-watershed-acre cost). For detailed analyses of each job, per-treatment-acre cost is appropriate for between-watershed comparisons and for extrapolating these costs to

Table 1.--Component jobs in the treatment of five Beaver Creek watersheds (see summary of treatment prescriptions for descriptions of watershed treatments)

Component job	Watershed--				
	9	12	14	16	17
Road and strip layout	X		X	X	
Marking			X	X	X
Log sale administration	X		X	X	
Pulp sale administration			X		
Clearing and thinning	X	X	X	X	X
Slash piling	X	X	X	X	X
Slash burning	X		X		
Chemical application		X			
Erosion control	X		X		

Table 2.--Component costs adapted for this analysis

Personnel	
GS grade	Hourly rate[1]
1	$2.58
2	2.93
3	3.30
4	3.72
5	4.15
6	4.63
7	5.13
8	5.68
9	6.27
Equipment	Cost per hour
TD-340	[2] 7.40
TD-15	[2] 14.91
D-6	[2] 13.42
D-7	[2] 16.64
Rubber tired dozer	[2] 8.59
Chain saw	[3] .42
Mist blower	[4] .30
Materials	Cost per unit
Flagging (roll)	[5] .22
Paint (gallon)	[5] 2.65
Grass seed (pound)	[6] .467
Diesel fuel oil, #2 (gallon)	[7] .17
Ponderosa pine seedlings (seedling)	[6] .046
Chemicals (gallon)	[5] .423

[1]GS grades taken from USDA General Schedule 5 U.S.C. 5332 (a) at step 1 level plus 18 percent overhead as of January 1972.

[2]Written communication from Roland L. Barger, Rocky Mountain Forest and Range Experiment Station. Consists of fixed and variable costs of operation without the operator.

[3]Obtained from Timber Staff Specialist at the Long Valley Ranger District, Coconino National Forest.

[4]Based on chain saw cost with adjustments for time of operation and maintenance.

[5]Obtained from the General Services Administration supply catalog.

[6]Obtained from Coconino National Forest records.

[7]General Services Administration price delivered to Happy Jack, Arizona.

other types of treatments. In addition, average per-watershed-acre cost was computed by multiplying each job cost by the number of acres per job and dividing by the total acres in the watershed. These costs are provided for comparing total treatment costs:

Watershed	Cost less travel
9	$26.94
12	79.95
14	44.58
16	66.79
17	58.91

The predictive models developed in this paper use per-watershed-acre units because the data collection system recognizes a uniform treatment pattern applied over the total watershed. On a per-treatment-acre basis, the cleared strip treatment (watershed 9) is similar to the clearcut (watershed 12). However, the per-watershed-acre treatment cost on watershed 9 is less because only one-third of the area was treated, or only one-third of the trees per acre were removed.

Table 3 presents the basic physical requirements in hours of supervision, labor, and equipment for each job and watershed on a treated-acre basis. These data are converted to the treated-acre dollar costs in table 4 by applying the unit costs in table 2. Material costs were presented directly in dollars in table 4 because the variety of items, such as rolls of flagging and gallons of paint, prevented expression in common units and because materials are a small percentage of total cost.

Tables 3 and 4 indicate that the strip layout jobs on watersheds 9, 14, and 16 covered a greater percent of the area than was actually cleared. This is due to crews surveying the total watershed for proper strip placements.

Major patterns discernible from table 4 involve the two largest jobs: clearing and/or thinning,[2] and slash piling. The clearing operations on watersheds 9 and 12 are quite consistent where both involve 100 percent removals on the treated acres. Because watersheds 14, 16, and 17 were thinned to various degrees, however, lesser degrees of removal were involved on a treatment-acre basis. The corresponding

[2]In this report, "clearing" refers to complete removal of all trees and "thinning" refers to partial tree removals. It should be noted that the cleared strips in Watersheds 9, 14, and 16, and the Watershed 12 clearcut are for experimental purposes, and do not reflect current National Forest operational cutting practices in the Southwest.

Table 3.--Supervision, labor, and equipment hours required to treat five Beaver Creek watersheds (WS)

Watershed treatment and job	Area treated	Portion of watershed treated	Time required per treated acre		
			Supervision	Labor	Equipment
	Acres	*Percent*	- - - - - - *Hours* - - - - - -		
WS-9: REGULAR 1/3 STRIPCUT	1141	100.0			
Road layout	3	.3	0	9.57	0
Strip layout	1141	100.0	0.03	.47	0
Log sale administration	219	19.2	0	1.01	0
Clearing cut strips	338	29.6	1.87	9.28	8.74
Slash piling	285	25.0	0	2.64	1.49
Slash burning	1121	97.9	.08	.34	.01
Erosion control	3	.3	0	7.00	0
WS-12: CLEARCUT	455	100.0			
Clearing cut strips	455	100.0	1.95	9.07	9.02
Slash piling	447	98.2	0	2.87	1.33
Chemical application	147	32.4	.88	2.95	2.02
WS-14: IRREGULAR 1/3 STRIPCUT	1350	100.0			
Strip layout	1310	97.0	0	.33	0
Marking	1310	97.0	.08	.33	0
Log sale administration	1310	97.0	.27	.20	0
Pulp sale administration	460	34.1	.13	.07	0
Clearing and thinning	1222	90.5	.35	4.91	3.91
Slash piling	1157	85.7	.03	1.94	1.67
Slash burning	1310	97.0	.03	.37	.02
Erosion control	35	2.6	.42	1.71	0
WS-16: IRREGULAR 1/2 STRIPCUT	252	100.0			
Strip layout	247	98.0	.33	.58	0
Marking	247	98.0	.23	.41	0
Log sale administration	247	98.0	1.57	.02	0
Clearing and thinning	247	98.0	1.41	5.72	5.74
Slash piling	247	98.0	.95	1.38	1.15
WS-17: SEVERE THIN	300	100.0			
Marking	300	100.0	0	.14	0
Thinning	294	98.0	.67	8.39	8.00
Slash piling	257	85.7	0	2.82	1.13

Table 4.--Treatment costs for five Beaver Creek watersheds (WS)

Watershed treatment and job	Area treated	Portion of watershed treated	Treated-acre cost: Super-vision	Labor	Equip-ment	Material	Total
	Acres	*Percent*					
WS-9: REGULAR 1/3 STRIPCUT	1141	100.0					
Road layout	3	.3	0	$52.69	0	$0.84	$53.53
Strip layout	1141	100.0	$0.17	2.65	0	.05	2.87
Log sale administration	219	19.2	0	6.08	0	0	6.08
Clearing cut strips	338	29.6	7.82	34.55	$3.67	0	46.04
Slash piling	285	25.0	0	9.85	19.10	0	28.95
Slash burning	1121	97.9	.44	1.29	.13	0	1.86
Erosion control	3	.3	0	26.04	0	0	26.04
WS-12: CLEARCUT	455	100.0					
Clearing	455	100.0	7.62	33.75	3.79	0	45.16
Slash piling	447	98.2	0	10.72	18.67	0	29.39
Chemical application	147	32.4	4.52	10.98	.60	2.22	18.32
WS-14: IRREGULAR 1/3 STRIPCUT	1350	100.0					
Strip layout	1310	97.0	0	1.52	0	.04	1.56
Marking	1310	97.0	.41	1.51	0	0	1.92
Log sale administration	1310	97.0	1.43	.74	0	0	2.17
Pulp sale administration	460	34.1	.71	.28	0	0	.99
Clearing and thinning	1222	90.5	1.80	18.27	1.64	0	21.71
Slash piling	1157	85.7	.18	7.22	12.41	0	19.81
Slash burning	1310	97.0	.17	1.49	.15	.04	1.85
Erosion control	35	2.6	2.19	6.20	0	4.67	13.06
WS-16: IRREGULAR 1/2 STRIPCUT	252	100.0					
Strip layout	247	98.0	1.23	1.94	0	.11	3.28
Marking	247	98.0	.86	1.38	0	.24	2.48
Log sale administration	247	98.0	5.86	.10	0	0	5.96
Clearing and thinning	247	98.0	5.26	21.25	2.41	0	28.92
Slash piling	247	98.0	3.56	6.76	17.18	0	27.50
WS-17: SEVERE THIN	300	100.0					
Marking	300	100.0	0	1.10	0	.03	1.13
Thinning	294	98.0	2.47	28.73	3.36	.50	35.06
Slash piling	257	85.7	0	9.82	17.52	0	27.34

lower costs for clearing and thinning on these watersheds suggest a direct relationship between cost and degree of timber removals. This idea is developed further in the predictive models section.

The slash piling costs are similar for all watersheds except watershed 14, where piling costs were less. Thirty-five percent of watershed 14 was commercially logged for pulpwood. The commercial removal of trees 8 to 11 inches d.b.h. reduced Forest Service costs.

Finally, it should be noticed that travel costs are not included. Since travel costs are a function of distance or time required to reach the working site, an additional means of estimating travel cost is required. Travel costs to watersheds 9, 12, and 14 consistently accounted for about 14 percent of the total costs. The Beaver Creek watersheds were an hour's drive (round trip) from the Ranger Station, so that traveling occupied 1/8 or 12.5 percent of a working day. The similarity between the two percentages indicates the labor intensiveness of the watershed treatments, and provides a rule-of-thumb for rough approximations of the expected proportion of travel cost to total cost if distance is known.

Predictive Models (Regression)

The two major components, cutting (clearing and/or thinning) and piling, are basic to any watershed treatment. They comprise an acreage-weighted average of 88 percent of the total treatment costs per acre for all watersheds. Cutting and piling activities are thus the mainstay of a cost predictor where costs are related to timber removals. The cutting activities are related only to basal area removed noncommercially. On the other hand, the piling activity follows both the commercial logger and the thinning crew, so piling costs are related to total basal area removed per acre from the watershed.

Table 5 contains the cutting and piling costs per watershed acre and the respective rates of timber removals per watershed acre to which they apply. In most cases, the commercial logging operation accounted for about 50 percent of the total removals. In the watershed 9 stripcut, for example, 32 percent of the total basal area was removed overall, with about half of that being removed commercially. However, a concerted effort on watershed 14 to fully utilize the timber through the sale of pulp and cordwood increased the commercial share. Thus the proportion of commercially valuable timber depends on management intensity. Also, sites of differing quality may have differing proportions of commercially usable timber. The proportion will also vary with time.

An initial, intensified watershed treatment removes undesirable trees even on poor sites, and puts the stand in good growing stock condition. Further harvests will benefit by having greater proportions of commercially usable timber. Hence, it is not only desirable but necessary to separate the cost model into two parts, cutting and piling activities, to emphasize the difference between commercial and noncommercial timber removals. Only then can differences in site quality, management intensity, and product flows over time be incorporated into the cost estimates.

Table 5.--Summary of per-watershed-acre cutting and piling costs vs. basal area of timber removals per watershed acre

Treatment	Average noncommercial basal area removed/acre (X)	Cutting costs (Y)	Average total basal area removed/acre (X)	Piling costs (Y)
	Ft^2		Ft^2	
WS-9: REGULAR 1/3 STRIPCUT	18	$13.64	38	$7.23
WS-12: CLEARCUT	56	45.16	105	28.87
WS-14: IRREGULAR 1/3 STRIPCUT	22	19.65	61	16.98
WS-16: IRREGULAR 1/2 STRIPCUT	36	28.35	78	26.95
WS-17: SEVERE THIN	47	34.36	90	23.42

The relationship between cutting costs and noncommercial basal area removed is presented in figure 5. Correlation analysis obtained a coefficient of determination (r^2) of 0.98, and a t test showed the y intercept not to be significantly different from the origin at the 0.05 level of significance. On the assumption, therefore, that no removal incurs no cost, the line is forced through the origin. The relationship $C_1 = 0.79BA_1$ is obtained where C_1 is cost per watershed-acre and BA_1 is the noncommercial basal area removed per watershed acre. This implies that it costs \$0.79 to cut noncommercial trees equivalent to 1 ft^2 of basal area from an acre.

A similar relationship was found for piling costs versus total removals (fig. 6). In this case, r^2 is 0.88, and again the intercept is not significantly different from zero at the 0.05 level. The relation is $C_2 = 0.28BA_2$ where C_2 is the predicted piling cost per watershed acre and BA_2 is total basal area removed per watershed acre. Again this implies that it costs \$0.28 to pile the slash accumulated per square foot of basal area removed by commercial and noncommercial operations.

Both basal area removals and costs are on a watershed-acre basis and the regression coefficients are the average cost per ft^2 of basal area removed. Since the regression passes through the origin, the coefficients are also equal to the average cost per ft^2 of basal area removed on a treated-acre basis.

The relationship derived thus far for the sum of cutting and piling costs is $C = 0.79BA_1 + 0.28BA_2$. An operationally suitable model would first have to be adjusted for the 12 percent of miscellaneous costs such as sale administration, marking, and other jobs. Thus, $C = 1.12\ (0.79BA_1 + 0.28BA_2) = 0.88BA_1 + 0.31BA_2$.

Typical ponderosa pine stands on Beaver Creek are lightly to moderately stocked. Although isolated patches of heavily stocked stands were cleared or thinned (notably on watershed 14), daily cost data were not identified closely enough on maps to determine cost-stocking relationships. Further research is needed to verify the model in heavily stocked stands, although no significant density-related economies or diseconomies of scale were noted.

Additional models were derived from data in table 3 converted to a per-watershed-acre basis (table 6). These models predict man-hours (supervision plus labor) and equipment hours for the cutting and piling activities. These are useful in that the managers are able to estimate cost from wage and equipment rental rates appropriate to the situation. The models (figs. 7, 8) are all linear with intercepts not significantly different from zero so they are fitted through the origin.

Table 6.--Summary of man- and equipment-hour requirements versus average basal area of timber removals per watershed acre

Treatment	Average basal area removed/acre: Noncommercial	Average basal area removed/acre: Total	Man-hours	Equipment hours
WS-9: REGULAR 1/3 STRIPCUT				
Cutting	18		3.30	2.59
Piling		38	.66	.37
WS-12: CLEARCUT				
Cutting	56		11.02	9.02
Piling		105	2.82	1.31
WS-14: IRREGULAR 1/3 STRIPCUT				
Cutting	22		4.76	3.54
Piling		61	1.69	1.43
WS-16: IRREGULAR 1/2 STRIPCUT				
Cutting	36		6.99	5.63
Piling		78	2.28	1.13
WS-17: SEVERE THIN				
Cutting	47		8.88	7.84
Piling		90	2.42	.97

The relationship obtained for man-hours of cutting time versus basal area removed noncommercially is $MH_1 = 0.20\ BA_1$ (fig. 7). Total predicted man-hours (MH_1) is composed of 18 percent supervision and 82 percent labor averaged over all watersheds. The equipment hours (EH_1) (fig. 7) were estimated by the relation $EH_1 = 0.16BA_1$. This estimate is based on the use of medium-sized power saws with brush bars, as are typically used by Forest Service thinning crews.

The relationships obtained for man-hours of piling time (MH_2) versus total basal area removed (fig. 8) is $MH_2 = 0.027BA_2$. For piling, the total predicted man-hours is composed of 10 percent supervision and 90 percent labor averaged over all watersheds. The equipment hours (EH_2) (fig. 8) were estimated by the relationship $EH_2 = 0.012BA_2$. This estimate of equipment hours is based on the use of medium-sized crawler tractors (TD-15, D6, D7). The use of other machines (Larson and Miller 1973) or improved equipment and methods may change the relationship. Watershed 14 was excluded from the equipment hours' prediction equation because a very intensive slash cleanup operation was prescribed and two tractors were used; a small tractor to pull slash out of thinned stands and a medium-sized tractor to

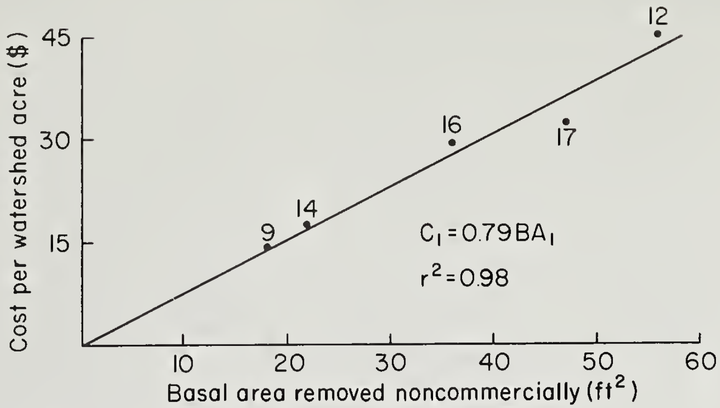

Figure 5.—Relationship between cutting cost and noncommercial basal area removals.

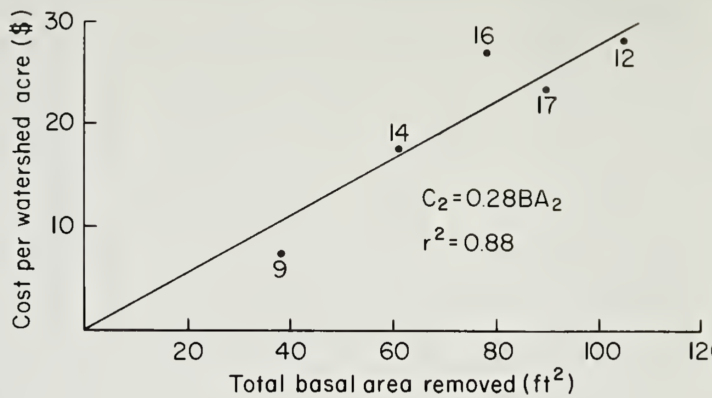

Figure 6.—Relationship between piling cost and total basal area removals.

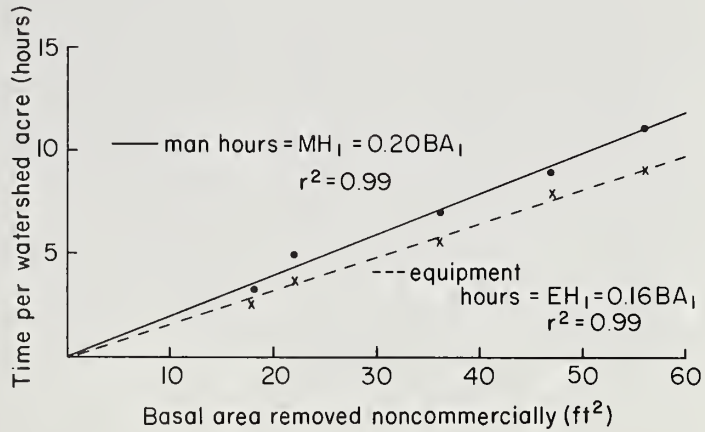

Figure 7.—Relationship between man and equipment hours for cutting and noncommercial basal area removals.

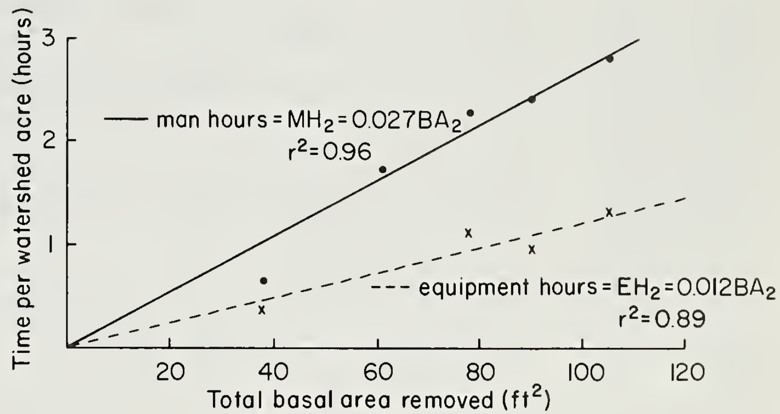

Figure 8.—Relationship between man and equipment hours for piling and total basal area removals.

pile this slash plus that in the cut-strips. Thus, some slash was handled twice and a proportion of the area was covered by both tractors.

Tabulated labor and equipment hours, for both cutting and piling operations at different levels of basal area removed (table 7), can be used in lieu of the predictive equations presented on page 8.

Table 7.--Hours per acre of labor and equipment required for cutting and piling activities as a function of basal area removals

Noncommercial basal area removed (Ft^2)	Cutting		Total basal area removed (Ft^2)	Piling	
	Labor	Equipment		Labor	Equipment
5	1.0	0.8	10	0.27	0.12
10	2.0	1.6	20	.54	.24
15	3.0	2.4	30	.81	.36
20	4.0	3.2	40	1.08	.48
25	5.0	4.0	50	1.35	.60
30	6.0	4.8	60	1.62	.72
35	7.0	5.6	70	1.89	.84
40	8.0	6.4	80	2.16	.96
45	9.0	7.2	90	2.43	1.08
50	10.0	8.0	100	2.70	1.20
55	11.0	8.8	110	2.97	1.32
60	12.0	9.6	120	3.24	1.44

Sensitivity Analysis

Each of the points in figures 5 and 6 is subject to wide fluctuation. It was anticipated that the sources of variation would be many and confounding. Thus, a more generalized indicator of cost was necessary so that many of these underlying sources such as labor, equipment, topography, and stand characteristics would average out over a large watershed. The degree of timber removals is an indicator of average cost. The variance of that cost is a function of daily variations, which in turn are related to the above sources encountered on a given day. The fact that the relationships obtained were meaningful indicates the merit of this approach.

Possible causes of cost variation were examined by sensitivity analysis to judge whether the addition of these causative factors would enhance the predictive power of the model. The first part of the sensitivity analysis is devoted to the influence of labor productivity and type of machinery used as general indicators of variability in costs. The second portion examines probable causes of variability as related to steepness of slope, size class, and distribution of trees.

Variation in Cost Due to Labor and Equipment

For each watershed, data were collected on a daily basis for all labor, equipment, and materials inputs (table 2). This information was examined by sensitivity analysis to determine daily variability within and between watersheds. The formula used for this analysis was developed by Miller (1971):

$$\text{Sensitivity Index (SI)} = \frac{\bar{Y}_i \; S_i}{\sum_i (\bar{Y}_i \; S_i)}$$

where

$\bar{Y}_i$ = the average cost per acre, and

S_i = the standard deviation of daily costs for the

i^{th} component, job, or watershed.

The entire sensitivity analysis is restricted to the cutting and piling operations and their component costs. Tests for sensitivity comparing jobs within each watershed indicate that, of the total variation in cost, cutting and piling on the average account for 95 percent. The cutting and piling operations are also common to all treatments.

Table 8 summarizes the sensitivity analyses. Variation around total cost per job acre (standard deviation) is a measure of the range of forest and working conditions and equipment used. In this case, the variation is substantial. A comparison between watersheds indicates where cutting and piling costs vary most relative to the other watersheds.

The two major trends indicated clearly by the component analysis in table 8 are that labor is responsible for most variation in the cutting operation, while the equipment component varies most in the piling operation. In the case of cutting activities, WS-9 shows the greatest variation. This may be due to slope, since WS-9 has more rugged terrain than the other watersheds. Conversely, WS-17, with relatively flat contours and uniform stand composition, has the least cutting cost variation.

Commercial pulpwood harvesting on WS-14 and WS-16 not only decreased cutting costs considerably, but also reduced variability of cost for cutting operations in the remaining stands. Cost variability was higher when cutting trees 8 inches and larger in diameter (table 8) because sawyers used power saws equipped with brush-cutting bars normally used for routine thinning work. These saws are unwieldy for felling larger trees.

Table 8.--Sensitivity analysis for clearing, thinning, and slash piling on five watersheds, showing average cost per job acre, standard deviation (SD), and sensitivity index (SI)[1]

Watershed	Supervision			Labor			Equipment			Total		
	Cost	SD	SI	Cost	SD	SI	Cost	SD	SI	Cost[2]	SD	SI
			Pct			*Pct*			*Pct*			*Pct*
WS-9: REGULAR 1/3 STRIPCUT												
Clearing	$7.82	$18.40	9.9	$34.55	$37.60	89.4	$3.67	$2.90	0.7	$46.05	$53.80	57.4
Piling	--	--	--	--	--	--	--	--	--	27.31	17.30	22.0
WS-12: CLEARCUT												
Clearing	7.62	5.90	6.1	33.75	20.70	92.9	3.79	2.10	1.0	45.16	26.60	27.8
Piling	--	--	--	--	--	--	--	--	--	29.40	30.60	42.0
WS-14: IRREGULAR 1/3 STRIPCUT												
Thin & clear	1.80	.80	1.4	18.27	6.00	97.9	1.64	.50	.7	21.73	7.10	3.6
Piling	.18	.80	.1	7.22	3.70	28.9	12.41	5.30	71.0	19.83	8.70	8.0
WS-16: IRREGULAR 1/2 STRIPCUT												
Thin & Clear	5.26	2.20	5.3	21.25	9.50	93.5	2.41	1.00	1.2	28.93	12.80	8.6
Piling	2.85	3.00	3.1	5.42	4.80	9.5	16.08	14.90	87.4	24.37	20.70	23.5
WS-17: SEVERE THIN												
Thinning	2.47	.60	2.1	28.73	2.70	96.7	3.36	.20	1.2	35.08	3.20	2.6
Piling	--	--	--	--	--	--	--	--	--	13.64	7.00	4.5

Note: "--" means not enough data for sensitivity analysis.

[1]All sources of variation accounted for; sensitivity indexes (SI) add to 100 percent for both within watershed and between watershed comparisons.

[2]May not add to total for the job in table 4 because downtime, a valid component of overall cost, is not pertinent to the sensitivity analysis and is not included.

Costs vary more for equipment than for labor in the piling jobs (table 8). Total average costs for piling are consistent between watersheds, but variation is considerable; the sensitivity analysis indicates that costs on WS-12 vary most. Piling costs on WS-12 varied because two different crawler tractors and a rubber-tired dozer were used. A small tractor with automatic transmission and hydraulic dozer was twice as efficient as the large tractor with manual shift and cable dozer, and was 6 percent more efficient than a rubber-tired dozer. Costs on WS-12 are discussed further in Miller and Larson (1973).

Variation in Cutting Costs Due to Slope and Stand Characteristics

To test the effects of slope and stand characteristics, it was necessary to characterize the daily observations by type of terrain and stands encountered that day. Work progress was mapped by units which required up to 2 weeks to be treated. Physical inventory data were used to characterize each working unit, and the daily costs for that unit were averaged as being typical of those inventory conditions. The working units were classified into eight strata on the basis of slope and number of trees in two aggregated size classes: (1) slopes greater than or less than 15 percent, (2) more or less than 50 trees per acre in the 8- to 11-inch diameter class, and (3) more or less than 750 trees per acre in the 1- to 11-inch diameter class. Stratification thus accounts for slope, density, and tree size class distribution. In addition, the two-stand composition criteria emphasize any cost differences when a thinning or slashing operation requires removal of larger trees normally removed by a commercial pulpwood operation. Once again, only the cutting and piling activities are included in the analysis.

Pulpwood harvesting greatly affected costs by leaving only a stand of uniformly small trees for thinning crews. WS-14 cutting costs were very consistent, and the sensitivity index showed evenly distributed variance between strata (table 8). The partial pulpwood sale minimized the effect of stand composition, leaving only the effects of slope. Because costs per acre were still quite consistent, both the Beaver Creek data and intuition suggest the inclusion of slope as a variable for determining cutting

costs only in extreme cases where slope exceeds 30 percent.

Analysis of data from watersheds 9 and 12, which did not have pulpwood sales, showed that cutting costs are affected by the number of trees with diameters exceeding 8 inches. This implies that the introduction of tree diameter as a variable helps explain variation in cost.

Variation in Piling Costs Due to Slope and Stand Characteristics

The sensitivity analysis for piling costs was not conclusive. It was thought that piling activities would be sensitive to slope, but the per-acre piling costs did not show this difference. The sensitivity index varied widely, however, which indicates that an unexplained factor, perhaps type and maneuverability of the dozer used (Miller and Larson 1973), is still causing variance.

Sensitivity Analysis Summary

The sensitivity analysis identified significant variation in daily per-acre costs due to the labor input in cutting activities and the machinery input in piling activities. Further analysis of the cutting operation rejected steepness of slope as a causal factor, and showed significance only for trees exceeding 8 inches in diameter. The analysis for the piling operation was unable to distinguish the effect of slope, and there were no discernible trends to suggest ways to improve the cost model.

Summary and Conclusions

Forest Service costs are summarized for five experimental watershed treatments in Arizona that differed in configuration and degree of timber removals. Data from the five watersheds were used to develop regressions which predict man and equipment hours, and treatment cost as a function of basal area removed. Clearing and thinning costs are related to the basal area removed noncommercially, while piling costs are related to total basal area removals including commercial logging. These relationships were then expressed as man and equipment hours of cutting and piling time to give regressions expressed in physical constants which can be updated with current wage and equipment operation rates.

The use of basal area removals as an indication of cost implicitly averages out a number of forest conditions, such as steepness of slope, which might affect costs. A sensitivity analysis was performed to measure the extent to which this averaging occurs, and to investigate possible avenues for refinement of the model. This analysis, which was focused on the variance in daily input requirements, showed that each of the data points in the cost relation does have a wide range of variation. It also revealed significant variation in daily per-acre costs due to the labor input in cutting activities and the machinery input in piling activities. Further analysis of the cutting operation rejected steepness of slope as a causal factor, and showed significance only for trees exceeding 8 inches in diameter which normally would be removed commercially for pulpwood. The analysis for the piling operation was unable to isolate a slope effect, and there were no discernible trends to suggest improvement of the cost model.

Additional cost data from heavily stocked stands with high rates of timber removals are needed to extend the model over the range of removals likely to be encountered in areas outside Beaver Creek.

A conceptual framework has been provided which explains the nature of watershed treatment costs, but which is also useful for planning purposes as well. The system can be applied in project planning where costs for timber stand improvement work must be estimated. Other applications include cost estimates in evaluating the effectiveness of alternative timber management prescriptions in multiple-use planning.

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1974. Cost analysis of experimental treatments on ponderosa pine watersheds. USDA For. Serv. Res. Pap. RM-116, 12 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo. 80521.

A regression model predicts thinning and piling costs as a function of the degree of timber basal area removed. Thinning costs are related to basal area removed noncommercially, while piling costs are related to total basal area removals including commercial logging. Sensitivity analyses indicate that the piling predictive models are representative for all but the most extreme conditions of slope steepness likely to be encountered in the Southwest. If thinning involved removal of trees larger than 8 inches in diameter, cost variability may be greater than that accounted for by the thinning model.

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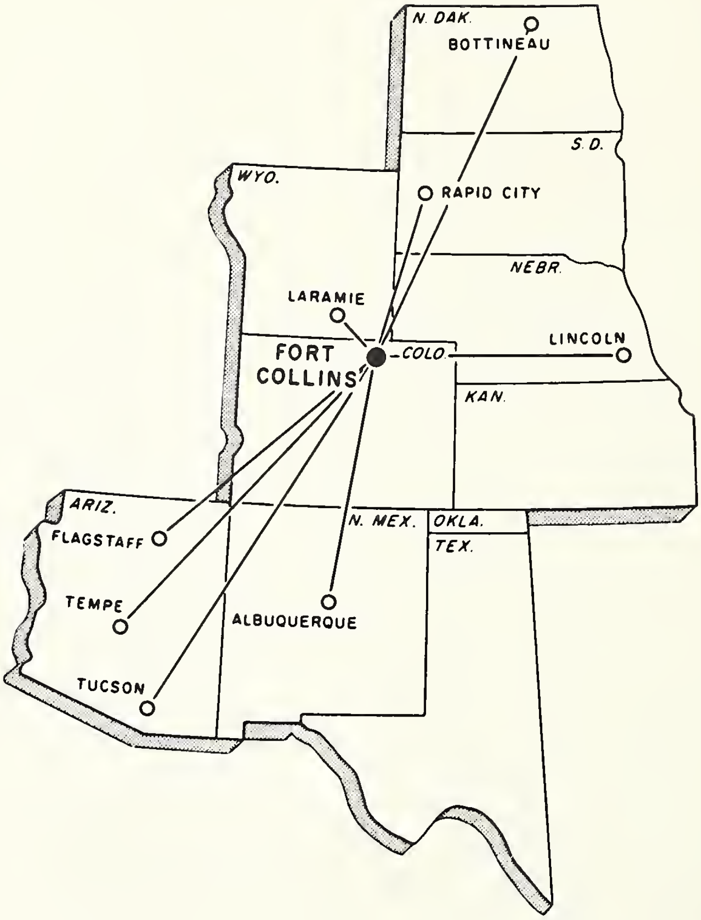
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